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EFFECT OF MALTING PROCESS DURATION ON MALTING LOSSES AND QUALITY OF WHEAT MALTS

– Research paper –

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Abstract: The study assesses impact of malting process duration on malting losses and quality of malts obtained from three varieties of winter wheat, i.e., *Elixer*, *Rockefeller* and *Gimantis*. The findings show that increased duration of the malting process (from 4 to 7 days) corresponded to greater total weight loss, with the most significant differences observed between 5-day and 6-day wheat malts. The qualitative analysis of the malts was carried out in accordance with EBC methodology. The assessments showed that the 5-day long malting process applied to the relevant wheat varieties resulted in production of high-quality malt with optimum malting losses observed in the case of *Elixer* and *Rockefeller* varieties. Slightly higher malting losses were identified in the case of *Gimantis*, and the malt obtained from this variety had very high contents of soluble protein (on average 5.34% d.m.) and Kolbach Index (average of 50.49%), which reflects high proteolytic activity during the grain malting process and a need to modify the malting process for this variety.

Key words: wheat grain, malting, malting losses, wheat malt quality

INTRODUCTION

Common wheat *(Triticum aestivum L.)* is the most extensively grown cereal crop in Poland and after maize it is the second most popular cereal crop worldwide (FAOSTAT 2019). Wheat grain is mainly used in milling and baking industries. As a result of advancements in wheat breeding, high-protein varieties are produced, to be milled into flour; these however are not used in production of wheat malt (Belcar et al., 2020). According to requirements defined by Polish malt-houses, wheat grain designated for malting and brewing processes should be characterized by high technological parameters, i.e., total protein content in the range of 9.5 – 11.5% d.m., grain size uniformity of 85% or higher and minimum germination energy of 95% (Belcar et al., 2020). Grain of winter wheat as a rule has lower total protein contents, hence the malt obtained from it presents higher extract potential and as a result the final product (beer) is satisfying for highly demanding (Boros et al., 2014).

Malting is a process during which controlled germination of caryopses takes place in optimum conditions (duration, temperature and air humidity). The process comprises the stage of steeping during which the grains uniformly absorb water in order to increase the moisture content to approx. 44% (Montanuci et al., 2017). Water uptake depends on the variety, grain size, nitrogen content and physiological condition of the material (Müller and Methner, 2015). Germination involves increased enzymatic activity and partial growth of the grain in an environment with adequate humidity and temperature, most commonly for the duration of 5-7 days. The temperature during germination process should be relatively low, in the range of 12-17ºC, to ensure high quality of the malt and to reduce the loss of grain weight (Müller and Methner, 2015). The next stage involves drying – in the process the desirable flavour of the product is achieved and water activity (a_w) is reduced owing to which the malt can be stored for a long time (Yang et al., 2021; Farzaneh et al., 2017; Kleinwächter et al., 2014; Schmitt et al., 2013; Gorzolka et al., 2012). Malting leads to numerous biochemical modifications in wheat grains, resulting in higher concentrations of phenolic compounds, greater antioxidant activity and improved chemical composition of the malt (Molinari et al., 2018).

Starch is the main reserve in wheat seeds; it breaks down e.g., into glucose and maltose which are absorbed by yeast during alcoholic fermentation (Strąk and Balcerek, 2016). The products of starch hydrolysis account for approximately 90% of the

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soluble components of wort (Meilgaard 1999). Extract potential of wheat malt is significantly affected by starch content in wheat grain as well as amylose/amylopectin ratio (Jin et al., 2011).
The factors responsible for the changes taking place in wheat grain include enzymes representing the group of hydrolases: β-amylases, α-amylases, β-glucanases, as well as proteases. The enzyme α-amylase is activated during the seed germination, the synthesis occurs in aleurone layer, and it hydrolyses α-1,4 glycosidic bonds inside the substrate. The products of degradation include maltotriose, isomaltose, maltose, glucose and dextrins. The enzyme β-amylase is present in dry wheat seeds, it is activated in the endosperm and during germination initially its concentration decreases and, subsequently on day 2 or 3 of the germination it increases again. This enzyme hydrolyses every other α-1,4 glycosidic bond, releasing β-maltose units from non-reducing ends of amylose chains. The enzyme is mainly responsible for the value of diastatic power of the malt (Montanuci et al., 2017; Gorzolka et al., 2012; Fennema et al., 2010; Schmitt and Marinac, 2007).
Breakdown of proteins by proteolytic enzymes is a complex process which continues to be investigated by researchers. Protein compounds present in wheat grains affect the process of mashing and fermentation. They are responsible for the contents for higher alcohols, stability of beer foam and other substances affecting the flavour and taste of beer. Proteins with large molecular weight contribute to the phenomenon of beer haze and affect the quality of beer foam, while proteins with lower molecular weight as well as amino acids have influence the taste of beer, and effectiveness of the fermentation process. In course of the malting process, endopeptidases break down proteins into polypeptides with lower molecular weight while exopeptidases break down products of degradation into amino acids, e.g., lysine, γ- aminobutyric acid and asparagine (Ding et al., 2018; Grassi et al., 2018; Xie et al., 2014; Jin et al., 2012).
The present study aims to identify effect of the duration of the malting process applied to wheat grain on the total loss of grain weight during the malting process; quality analysis of the obtained malts and to determine the optimum duration of the malting process for analyzed varieties of winter wheat.

MATERIAL AND METHODS

Material

The research material comprised grains of three winter wheat varieties: *Elixer, Rockefeller* and *Gimantis* (Class C wheat cultivars), produced in course of a rigorous field experiment conducted in the vegetation period of 2019/2020 in Jelcz-Laskowice (51°21´N; 17°35´W), a facility administered by the Department of Herbology and Plant Cultivation Techniques of the Institute of Soil Science and Plant Cultivation State Research Institute in Wrocław.

Analysis of the commodity characteristics of wheat grains

The wheat grains were assessed for a number of characteristics, i.e., moisture content in the grain determined using oven drying method in accordance with PN-EN ISO 712:2012; bulk density of grains (PN-EN ISO 7971-3:2019-03); 1000 grain weight; total protein content determined using the Kjeldahl method; grain uniformity assessed using Steinecker-Vögl sorter, whereby uniformity was assumed to be reflected by the proportional share of the grains remaining in the sieves, mesh size of 2.5 and 2.8 mm jointly.

In order to assess the materials for their germinative energy and germination rate, samples of 100 grains were collected from each batch (3 x 100 grains) and germinationed in accordance with Aubry Method (3.6.1 EBC Method).

Malt preparation

Wheat grain was cleaned on a *Vögel* sieve and a grain fraction > 2.5 mm (320 g samples) was selected for malting. The material was placed in a climate cabinet at a relative air moisture of 90% and a temperature of 15° C ± 1°C on metal sprouting plates covered with filter paper and soaked until the humidity reached 45% (by spraying with tap water at a temperature of 15°C ± 1°C with sprayer twice a day at 12-hour intervals). After the specified germination time (4, 5, 6, 7 days, respectively), the raw material was dried in a laboratory dryer for the following time: 15h - 40°C, 3h - 50°C, 3h - 65°C and 2h - 80°C, and then removed roots. The malting of wheat grain was carried out in the laboratory of the Department of Agricultural and Food Engineering at the University of Rzeszow.

Determination of malting losses

The total natural malting loss in the wheat grains was determined as a percentage value reflecting the difference in the weight of 1000 grains (as per dry

matter) measured before and after the malting process. The total malting loss is affected by the decrease in the grains weight associated with the modifications resulting from wheat germination.

Analysis of the malts and worts

In the tested malts, the moisture was determined by 4.2 EBC Method, protein content was determined by the Kjeldahl method (4.3.1 EBC Method), previously grinding the malt to a particle size of 2 mm in a Cemotec disc mill from FOSS. Then the congress mashing was made in accordance with 4.5.1 EBC Method (Analytica EBC, 2004). The diastatic power was determined in the wort in accordance with 4.12.1 EBC Method whereas, degree of final fermentation was determined in accordance with 4.11.1 EBC Method.

The content of soluble protein was measured (EBC Method 4.9.1) and Kolbach index was calculated. In the laboratory wort, was examined of viscosity of the wort, extract in the dry malt mass, runoff time, and pH according to 4.6.1 EBC Method (Belcar et.al., 2020).

Statistical analysis

All the analyses were performed in three parallel replications. The results were computed using Statistica 13.3 software. To interpret the results, one-way analysis of variance ANOVA (Tukey's test) was applied, with significance level at $\alpha = 0.05$, for the specific grain characteristics, relative to the wheat variety. Effects of wheat variety and duration of malting process on the volume of malting loss and quality of the wheat malts were assessed using multi-factor analysis of variance (Tukey's HSD), with the assumed significance level at $\alpha = 0.05$.

RESULTS AND DISCUSSION

In Poland more and more malt producers and beer makers are interested in production of wheat beer. To ensure fine sensory properties as well as physical and chemical characteristics of this type of beer it is necessary to adequately select the raw material intended for malting. Wheat grains selected for malting should present high technological value.

Moisture content in the wheat grain examined was in the range of 11.23 – 11.57% (Table 1). Lower water content in grain corresponds to greater risk of transversal cracking of endosperm due to higher stress which occurs during the steeping process and subsequently is intensified by the drying process; this leads to reduced quality of the material (Woźniak and Grundas, 2006; Woźniak 2004).

Protein content is a characteristic which significantly affects the malt and the final product, i.e., beer. Total protein content in wheat grains, just like in barley grains, should be in the range of 9.5-11.5% d.m. (Belcar et al., 2020). Excessive total content of protein may lead to lower extract potential of the malt due to insufficient "loosening" of the protein (Jin et al., 2008). Furthermore, during the conditioning of beer made from malt with higher protein content there may be a greater risk of excessive haze and sediment formation (wheat beers tend to be naturally opalescent). On the other hand, low protein content in the grain designated for malting results in insufficient quantity of nitrogen compounds necessary for brewing yeast metabolism, due to which the sugars available are not effectively processed into ethyl alcohol and efficiency of the fermentation process is decreased. The total contents of protein in the grains of *Elixer* (11.77% d.m.) and *Rockefeller* varieties (12.07% d.m.) were slightly higher while in the grain of *Gimantis* wheat variety (11.07% d.m.) the relevant value was in line with the norm.

Grain size uniformity is one of the most important quality parameters of raw material designated for malting. Healthy grains uniformly absorb water during the steeping process, and consequently they germinate evenly and during the drying process they also dehydrate in an optimum manner. Raw material designated for malt production should have grain size uniformity at a minimum level of 85%. Due to the unfavourable weather conditions during the season of 2019/2020, grain of the wheat varieties taken into account in the study did not meet the high-quality requirements, which was particularly visible in the case of *Rockefeller* variety (59.60%; Table 1.). In such case the material must be purified, so that grains which do not meet the required dimensions (>2.5 mm i.e., inferior, damaged as well as other contamination) are removed; this is associated with higher costs of malt production.

Seed germination is a complex process linked with changes in the chemical composition of the grain resulting from the action of hydrolytic, proteolytic and other enzymes, which mediate production of substances desirable in the final product, i.e., beer-making (Kleinwächter et al., 2014; Schmitt et al., 2013). Germinative energy in the case of grains designated for malting should not be lower than 95%; otherwise, non-uniform germination of the malt adversely affects its extract potential and leads to longer duration of the mashing process. Grains of the three wheat varieties (*Elixer, Rockefeller* and *Gimantis*) were found with high germinative energy and germination rate exceeding 95% (Table 1).

Table 1. Mean values of quality parameters in the grains of three winter wheat varieties ($\bar{x}$±SD)

	Winter wheat Elixer variety	***Winter wheat Rockefeller variety***	***Winter wheat Gimantis variety***
Moisture [%]	11.27^{a}±0,12	11.57^{a}±0,06	11.23^{a}±0,23
Total protein [% d.m.*]	11.77^{a}±0,15	12.07^{a}±0,06	11.07^{b}±0,15
Hectolitre weight [kg·hL^{-1}]	71.20^{a}±1,30	68.57^{a}±0,21	70.63^{a}±1,32
Grain size uniformity [%]	73.40^{b}±2,46	59.60^{c}±1,06	78.47^{a}±1,59
Germinative energy after 72 hours [%]	95.00^{a}±2,65	95.00^{a}±4,36	96.00^{a}±2,00
Germination rate after 120 hours [%]	96.00^{a}±0,00	95.00^{a}±1,00	97.00^{a}±2,65

*various letters in the rows show significance of the differences at α=0.05

* [% d.m.] – percent of dry matter

Malting loss

Total malting loss reflects the decrease in wheat grain weight resulting from the malting process and associated with the modifications leading to germination. In the group of 4-day malts, the lowest total malting loss (4.20% d.m.) was found in grain of *Elixer* variety, where 54% of the total loss was related to root weight (Table 2.). In the case of 4-day malt produced from wheat of *Rockefeller* variety, the findings showed a slightly greater loss of grain weight associated with formation of roots (2.99% d.m.), while in 4-day malt from *Gimantis* wheat variety, over 50% of the total loss was accounted by the decrease in grain weight (Table 2). In the group of 5-day malts obtained from the three wheat varieties, similar total losses were identified, the related mean value amounted to 5.48% d.m., with grain weight loss accounting for a minimum of 50.60% d.m. of the total weight loss in grain subjected to malting process (Table 2.). A study conducted by Belcar et al. (2020) assessed 5-day malts and identified lower total malting losses, amounting to 3.57% d.m. in the case of wheat malt from *Elixer* variety, and 3.30% d.m. in malt from *Rockefeller* variety. Decrease in grain weight associated with formation of roots in both studies was similar while significant differences were observed in grain weight loss (1.43% d.m. and 1.24% d.m. in grains of *Elixer* and *Rockefeller* varieties, respectively). These differences may be connected with decreased plumpness of grain in the present study compared to the previous work (adverse effect of weather conditions during plant growth). Although the wheat grain was sorted and grain fraction >2.5 mm was selected for malting, relatively higher malting loss was identified.

The findings related to 6-day wheat malts showed relatively high total loss, on average exceeding 9.30% d.m., except for malt obtained from grain of *Rockefeller* variety, which was found with lower decrease in grain weight related to formation of roots (4.90% d.m.) and lower grain weight loss (3.46% d.m.; Table 2). The group of 7-day wheat malts was found with total loss on average amounting to 10.67% d.m. The lowest total loss was observed in the case of *Gimantis* variety; here, the decrease in grain weight related to root formation amounted to 5.39 % d.m. and grain weight loss to 5.00% d.m. (Table 2.). Longer duration of the malting process leads to increased total loss of grain weight due to the growth of greater number of roots of the new developing plant. A comparison of the present findings related to 7-day wheat malts with results identified in another study (procedure "A" – air humidity 85% and temperature of the malting process 14.5°C) conducted by Krstanović et al. (2021) shows that all the varieties subjected to malting in the present study were characterised by significantly higher total malting loss (6.57% d.m.) and root weight loss (4.80% d.m.).

Table 2. Effect of malting process duration on 1000-grain weight, and natural losses in the wheat malts ($\bar{x}$±SD)

Cultivar	**Wheat malt**	**Mean TGW for grain [g d.m.*]**	**Mean TGW for malt [g d.m.]**	**Total loss [% d.m.]**	**Weight loss – roots [% d.m.]**	**Weight loss – grains [% d.m.]**
Elixer	4 - day	36.63^{de}±0,08	35.09^{d}±0,06	4.20^{f}±0,22	2.27^{f}±0,10	1.93^{f}±0,07
	5 - day	36.12^{f}±0,20	33.87^{f}±0,16	5.45^{de}±0,27	2.69^{de}±0,17	2.76^{e}±0,14
	6 - day	36.40^{ef}±0,16	33.00^{h}±0,04	9.34^{b}±0,21	5.11^{bc}±0,08	4.23^{c}±0,06
	7 - day	36.45^{ef}±0,13	32.53^{i}±0,10	10.75^{a}±0,13	5.43^{ab}±0,20	5.32^{ab}±0,19
Rockefeller	4 - day	39.77^{a}±0,11	37.73^{a}±0,14	5.13^{e}±0,08	2.99^{d}±0,09	2.14^{f}±0,08
	5 - day	37.07^{cd}±0,23	35.08^{d}±0,09	5.37^{de}±0,14	2.56^{ef}±0,10	2.81^{e}±0,08
	6 - day	38.76^{b}±0,14	35.52^{c}±0,08	8.36^{c}±0,13	4.90^{c}±0,09	3.46^{d}±0,15
	7 - day	37.48^{c}±0,16	33.40^{g}±0,12	10.88^{a}±0,13	$5.36a^{ab}$±0,11	5.52^{a}±0,13
Gimantis	4 - day	39.40^{a}±0,15	37.22^{b}±0,13	5.53^{de}±0,19	2.73^{de}±0,19	2.80^{e}±0,12
	5 - day	36.94^{d}±0,12	34.86^{d}±0,11	5.63^{d}±0,16	2.95^{d}±0,09	2.68^{e}±0,25
	6 - day	37.56^{c}±0,20	34.02^{f}±0,08	9.42^{b}±0,10	5.59^{a}±0,13	3.83^{cd}±0,12
	7 - day	38.40^{b}±0,28	34.41^{e}±0,17	10.39^{a}±0,15	5.39^{ab}±0,11	5.00^{b}±0,17

*various letters in the rows show significance of the differences at α=0.05

* [g d.m.] – gram of dry matter

Changes in protein content during the malting process

Changes which take place during the malting process lead to modifications in protein compounds (mainly gliadin and glutenin) into amino acids and low-molecular-mass proteins (Guo et al., 2019). Protein compounds are used as a substrate nourishment for the new plant (Błażewicz et al., 2013). The decrease in total protein contents in malted grain, compared to non-malted grain (loss), should not exceed 0.30 – 0.50% (value for malting barley; Szwed et al., 2009). In the group of wheat malts investigated here, the lowest decrease in total protein content was identified in the malts produced from *Elixer* variety; the relevant value ranged from 0.07% (in 4-day malt) to 0.47% (in 7-day malt). In 7-day malt obtained from *Rockefeller* variety the decrease in total protein content amounted to 0.60%, while the remaining malts were found with a decrease in this parameter ranging from 0.17 to 0.37%, depending on the duration of the malting process. The findings related to wheat malts from *Gimantis* variety show 0.04% and 0.27% decrease in total protein contents in 4-day and 5-day malts, respectively, while the 6-day and 7-day malts were found with the highest decrease in total protein contents, compared to all the wheat malts investigated (0.70 and 0.84%, respectively). The study by Belcar et al. (2020) found 5-day wheat malts obtained from *Elixer* and *Rockefeller* varieties with a decrease amounting to 0.30%, and 0.40%, respectively. Boros et al. (2014) in their study identified mean decrease in total protein content amounting to 0.59%, compared to the value of 1.22% reported by Weiner et al. (2008).

Optimum total protein contents in wheat malts are in the range of 11.0-13.0% d.m. (Faltenmaier et al., 2014); this way adequate amount of nitrogen compounds, necessary for normal functioning of metabolism, is provided to beer yeast. Excessively high and excessively low protein contents in wheat malt adversely impact effectiveness of technological processes (e.g., brewing) and quality of the produced beer (poorer extract, alcohol content and sensory properties of the final product). Compared to barley grain, wheat grain contains greater amounts of proteins with high molecular mass; these significantly affect haze formation in wheat beer as well as stability of beer head (Depraetere et al., 2004). In the present study total protein contents were consistent with the norm in malts produced from grains of *Elixer* variety (from 11.70% d.m. in 4-day malt to 11.30% d.m. in 7-day malt; Table 3.) and from *Rockefeller* variety (from 11.90% d.m. to 11.47% d.m., respectively; Table 4.). The lowest total protein contents were found in malts made from *Gimantis* variety (from 11.03% d.m. in 4-day malt to 10.23% d.m. in 7-day malt; Table 5.). Comparative assessment of 5-day malts produced from grains of *Elixer* and *Rockefeller* varieties in the present study and the malts obtained in the previous year shows that wheat malt obtained from *Rockefeller* variety had higher total protein content (Belcar et al., 2020). The difference is associated with the higher total protein contents in wheat grain of *Rockefeller* variety produced during the 2019/2020 growth season, given the fact that the decrease in protein content in the grain resulting from the malting process was similar. Wheat malts produced by Weiner et al. (2008) were found with mean total protein content of 13.28% d.m., while a mean value of 14.80% d.m. was reported by Boros et al. (2014).

The ultimate flavour of beer is affected by the contents of soluble protein which passes into the wort during the mashing process. Depending on the wheat variety and duration of the malting process, the contents of soluble protein ranged from 4.47% d.m. in 4-day malt from grains of *Gimantis* variety to 5.85% d.m. in 5-day malt produced from the same wheat variety (Table 5). As regards the remaining varieties, a slight increase was observed in the contents of proteins soluble in wort, corresponding to longer duration of the malting process (in wheat of *Rockefeller* variety), or the contents increased with longer duration of malting (in the case of *Elixer* variety the lowest value was observed in 5-day malt). The wheat malts produced in the previous year were found with relatively lower contents of soluble proteins, ranging from 3.72% d.m. in the case of *Rockefeller* variety to 3.83% d.m. in *Elixer* variety (Belcar et al., 2020).

Kolbach Index is a measure reflecting the degree of protein "loosening" and it shows the rate at which nitrogen compounds pass from malt to wort as a result of mashing. In the case of barley malts, Kolbach Index should be in the range of 38-45% (Michałowska 2017). For wheat malts the optimum value of proteolytic modification is slightly lower, amounting to 37-40%, however a broader range is also acceptable (from 35 to 45%; Faltenmaier et al., 2014). Infusion mashing is applied to malts with Kolbach Index of 38-42%; malts with lower KI values (33-37%) are used in production of such types of beer as pilsner and lager, while malts with KI exceeding 45% are used in production of low-alcohol beer (Belcar et al., 2020). In the present study, out of all the malts from winter wheat varieties, the lowest KI values were identified in 4-day malts produced from grain of *Rockefeller* (42.94%) and *Gimantis* (40.53%) varieties, and in 5-day malt from grain of *Elixer* variety (40.50%)

(Table 3.-5.). Furthermore, 5-, 6- and 7-day malts from grain of *Gimantis* variety were found with very high KI (over 53.00%; Table 5.). The study by Belcar et al. (2020) showed Kolbach Index of 33.01% in the case of malts from *Elixer* variety and 33.21% in malts from *Rockefeller* variety. Li et al. (2017) produced wheat malts with Kolbach Index of 33.00%, while the related values reported by Psota et al. (2018) were in the range of 30.80-40.70%, and by Jin et al. (2012) in the range of 31.40-45.50%.

Enzymatic activity of the obtained malts

During the malting process, starch contained in wheat grain is hydrolysed to various glucose oligomers as a result of the activity of hydrolytic enzymes, which is reflected by the parameter of diastatic power and expressed in Windlich-Kolbach degrees (Boros et al., 2014). Lower activity of enzymes from the group of hydrolases corresponds to higher starch content in the produced malt; the starch will not be broken down due to which the degree of final fermentation will be decreased (Gorzelany et al., 2019). The varied duration of the malting process did not significantly affect the parameter of diastatic power in the wheat malts investigated in the present study. The highest value of this parameter was found in malts obtained from wheat grain of *Elixer* variety (320-331 ºWK, Table 3.). In the case of the malts produced from grain of *Gimantis* variety, diastatic power ranged from 307 to 315 ºWK (Table 4.).

Table 3. Effect of malting process duration on mean values of quality parameters in the malts and wort from wheat of *Elixer* variety ($\bar{x}$±SD)

The malt parametres	Malt obtained from winter wheat *Elixer* variety			
	4 - day	**5 - day**	**6 - day**	**7 - day**
Moisture [%]	4.06^{d}±0,06	4.43^{bc}±0,13	4.71^{ab}±0,14	4.70^{ab}±0,08
Total protein in malt [% d.m.*]	11.70^{ab}±0,44	11.63^{ab}±0,29	11.37^{abc}±0,32	11.30^{abc}±0,30
Soluble protein in malt [% d.m.]	4.97^{e}±0,06	4.71^{f}±0,08	5.42^{bc}±0,12	5.46^{bc}±0,14
Kolbach Index [%]	42.47^{h}±0,10	40.50^{i}±0,12	47.67^{d}±0,07	48.32^{c}±0,04
Diastatic power [ºWK]	320.00^{ab}±7,21	331.00^{a}±9,64	325.00^{a}±6,00	330.00^{a}±11,27
pH	5.67^{ab}±0,12	5.75^{a}±0,07	5.69^{ab}±0,07	5.63^{ab}±0,08
Final attenuation [%]	77.27^{d}±0,86	82.37^{a}±0,95	82.33^{a}±0,65	77.53^{cd}±0,90

*various letters in the rows show significance of the differences at α=0.05

* [% d.m.] – percent of dry matter

Table 4. Effect of malting process duration on mean values of quality parameters in the malts and wort from wheat of *Rockefeller* variety ($\bar{x}$±SD)

The malt parametres	Malt obtained from winter wheat *Rockefeller* variety			
	4 - day	**5 - day**	**6 - day**	**7 - day**
Moisture [%]	4.99^{a}±0,12	4.86^{a}±0,07	4.84^{a}±0,06	4.82^{a}±0,09
Total protein in malt [% d.m.*]	11.90^{a}±0,44	11.80^{ab}±0,17	11.70^{ab}±0,20	11.47^{abc}±0,15
Soluble protein in malt [% d.m.]	5.11^{e}±0,09	5.17^{de}±0,05	5.14^{d}±0,04	5.38^{cd}±0,08
Kolbach Index [%]	42.94^{g}±0,11	43.81^{f}±0,12	43.93^{f}±0,09	46.90^{e}±0,12
Diastatic power [ºWK]	296.00^{b}±9,54	305.00^{ab}±9,85	309.00^{ab}±9,17	298.00^{b}±6,24
pH	5.65^{ab}±0,10	5.48^{ab}±0,11	5.58^{ab}±0,17	5.60^{ab}±0,25
Final attenuation [%]	79.13^{bcd}±1,16	80.13^{abc}±0,90	82.50^{a}±0,75	79.93^{abcd}±1,16

*various letters in the rows show significance of the differences at α=0.05

* [% d.m.] – percent of dry matter

Table 5. Effect of malting process duration on mean values of quality parameters in the malts and wort from wheat of *Gimantis* variety ($\bar{x}$±SD)

The malt parametres	Malt obtained from winter wheat *Gimantis* variety			
	4 - day	**5 - day**	**6 - day**	**7 - day**
Moisture [%]	4.21^{cd}±0,14	4.13^{cd}±0,09	4.78^{a}±0,15	4.83^{a}±0,15
Total protein in malt [% d.m.*]	11.03^{bcd}±0,32	10.80^{cd}±0,20	10.37^{d}±0,31	10.23^{d}±0,35
Soluble protein in malt [% d.m.]	4.47^{g}±0,23	5.85^{a}±0,14	5.62^{ab}±0,10	5.43^{bc}±0,11
Kolbach Index [%]	40.53^{i}±0,23	54.17^{a}±0,09	54.19^{a}±0,06	53.08^{b}±0,06
Diastatic power [ºWK]	314.00^{ab}±9,71	315.00^{ab}±13,20	307.00^{ab}±5,29	312.00^{ab}±7,94
pH	5.53^{ab}±0,10	5.34^{b}±0,15	5.32^{b}±0,10	5.44^{ab}±0,19
Final attenuation [%]	80.03^{abcd}±0,71	80.87^{ab}±0,93	80.07^{abc}±0,81	80.37^{ab}±1,01

*various letters in the rows show significance of the differences at α=0.05

* [% d.m.] – percent of dry matter

The lowest enzymatic activity was identified in the malts produced from wheat grain of *Rockefeller* variety (296-309 ºWK, Table 5). Weiner et al. (2008) obtained wheat malt with diastatic power of 286 ºWK; the related mean values reported by Boros et al. (2014) and Li et al. (2017) amounted to 390 ºWK, and 369 ºWK, respectively; while Jin et al. (2012) produced wheat malts with diastatic power in the range from 384 to 496 ºWK. The study by Belcar et al. (2020), assessing 5-day malts from *Elixer* and *Rockefeller* wheat varieties, identified the diastatic power of 427 ºWK and 422 ºWK in the respective malts. An increase in the parameter of diastatic power may result from intensified use of nitrogen fertilisers, these however contribute to decrease in extract potential of malts (Pecio 2002).

Differences in the degree of final fermentation were related to both the wheat variety used to produce the malt and to the duration of malting process. Wheat malt as a rule is found with higher extract potential (because of the lack of husk) but at the same time with lower final fermentation of wort (Beck 2005). The degree of final fermentation to the highest extent is related to the wheat variety, and to a lower extent by the technique applied in the malting process or by other factors (Krstanović et al., 2019). The highest degree of final fermentation was identified for 5-day wheat malts, with an exception of the malt obtained from *Rockefeller* variety; in this case the highest degree of final fermentation was found for 6-day malt. The lowest degree of final fermentation was identified for 4-day malts, irrespective of the wheat variety. The study by Belcar et al. (2020) reported degree of final fermentation for 5-day malts amounting to 82.80% in the case of *Elixer* and to 79.79% in *Rockefeller* variety. Psota et al. (2018) identified mean degree of final fermentation for 6-day wheat malts ranging from 78.60 to 81.40%. Boros et al. (2014) assessed 7-day malts obtained from grains of winter wheat and reported degree of final fermentation ranging from 81.80 to 84.30%.

The value of pH in the wort impacts activity of hydrolytic and proteolytic enzymes - they are most effective if pH is lower than 5.6 (optimum value in the range of 5.2 – 5.3) which is related to the quality of the final product, i.e., beer. Optimum enzymatic activity makes it possible to obtain malt with high extract potential or wort with lower viscosity (Pater et al., 2019; Nowak et al., 2009). The lowest pH values were identified in the case of malts produced from wheat grains of *Gimantis* variety (from 5.32 in 6-day malt to 5.53 in 4-day malt, Table 5.), while the malts made from wheat grain of *Elixer* variety were found with the highest pH value of the wort, ranging from 5.63 in the case of 7-day malt to 5.75 in 5-day wheat malt (Table 3.).

Changes in extract potential of the malt relative to the malting time

Extract potential of malt is recognised by malt producers and beer makers among the essential quality parameters which make it possible to determine the optimum amount of raw material to be used in order to ensure maximum productivity of the brewhouse and consequently achieve economic effectiveness of the brewery (Belcar et al., 2020; Gorzelany et al., 2019). The term extract potential corresponds to the chemical compounds contained in the malt and passing to the wort during the mashing process. Extract potential is significantly affected by the parameters of the mashing process and activity of hydrolases and proteases (Boros et al., 2014). Extract potential of wheat malts should amount to 83% or more (Faltenmaier et al., 2014). Irrespective of the wheat variety investigated, the highest extract potential was found in 6-day malts and the lowest in 4-day malts. Furthermore, the varied duration of the malting process did not result in decreased extract potential of the malts (in all of these the parameter met the normative value). In the group of 6-day malts the highest extract potential was identified in the malt produced from wheat grain of *Gimantis* variety (88.10% d.m.), and in the group of 4-day malts the lowest extract potential was found in the malt obtained from *Rockefeller* variety (83.40% d.m., Figure 1). The study assessing 5-day wheat malts obtained from *Elixer* and *Rockefeller* varieties showed extract potential of 81.85% and 81.71% d.m., respectively (Belcar et al., 2020). Extract potential of 7-day wheat malts, reported by Boros et al. (2014), on average amounted to 83.40% d.m. Extract potential identified in wheat malts by Jin et al. (2012) was in the range of 79.30 – 82.30% d.m.; in the study by Depraetere et al. (2004) the relevant values ranged from 75.00% to 86.90% d.m., while Psota et al. (2018) reported mean extract potential of 6-day wheat malts on average amounting to 85.40% d.m. Extract potential of malts is significantly related to cultivar characteristics and to a lesser degree the parameter is affected by variable agricultural techniques and technologies applied (Węgrzyn and Bichoński, 2001).

Changes in wort viscosity relative to the malting time

The value of wort viscosity is significantly affected by the contents of soluble forms of arabinoxylans and β-glucans (and to a lesser degree by other non-starch polysaccharides), which reduce the filtration

rate (Szwajgier and Targoński, 2005). Viscosity of wheat malts should be below 1.80 mPa·s (Faltenmaier et al., 2014). Irrespective of the duration of the malting process applied to grain of *Elixer* variety, the worts were found with very high viscosity ranging from 2.47 mPa·s in 5-day malt to 2.65 mPa·s in the case of 6-day malt (Figure 2.). As regards the remaining wheat varieties, the lowest viscosity was identified in worts obtained from 6-day wheat malts, namely 1.99 mPa·s in the case of the malt produced from *Rockefeller* and 1.41 mPa·s in the case of the malt obtained from *Gimantis* wheat variety. Additionally, viscosity of wort obtained from 5-day malt produced from *Gimantis* wheat variety also met the normative value (1.80 mPa·s; Figure 2).

The study by Belcar et al. (2020), assessing 5-day wheat malts, reported viscosity of 2.65 mPa·s in wort obtained from *Elixer*, and 2.71 mPa·s in wort produced from *Rockefeller* wheat variety. Psota et al. (2018) assessed 6-day wheat malts and observed wort viscosity in the range of 1.687 – 2.314 mPa·s. On the other hand, in the study by Boros et al. (2014) worts produced from 7-day malts were found with mean viscosity of 1.79 mPa·s. Increased viscosity of wheat malts may be linked with insufficient cytolysis of the malt.

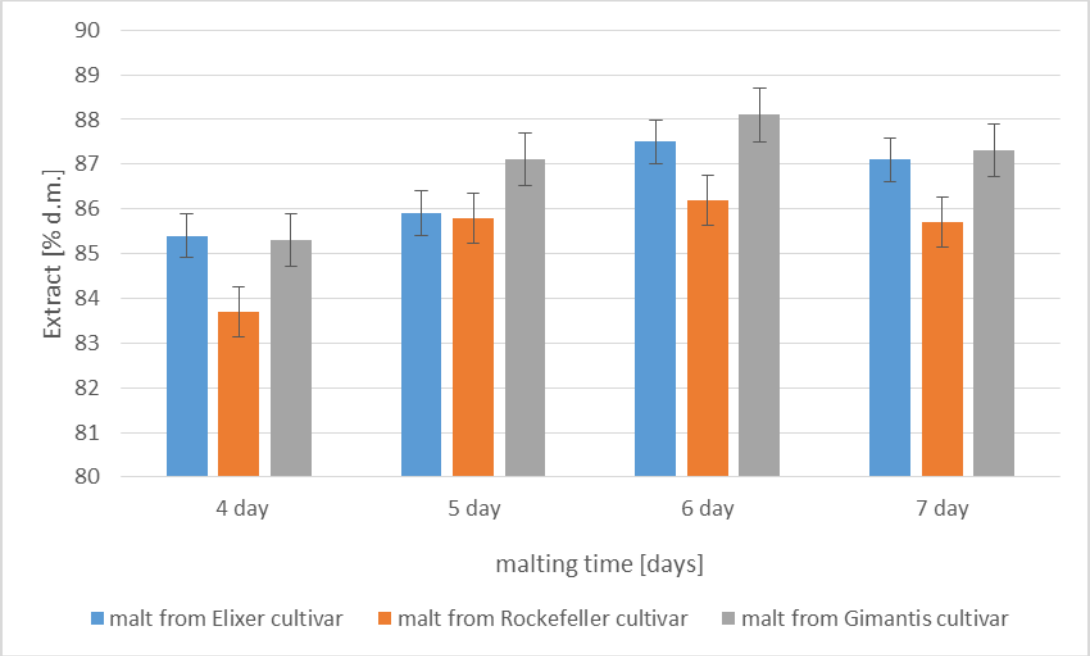


Figure 1. Effect of the malting time and wheat variety on the content of extract in the malt

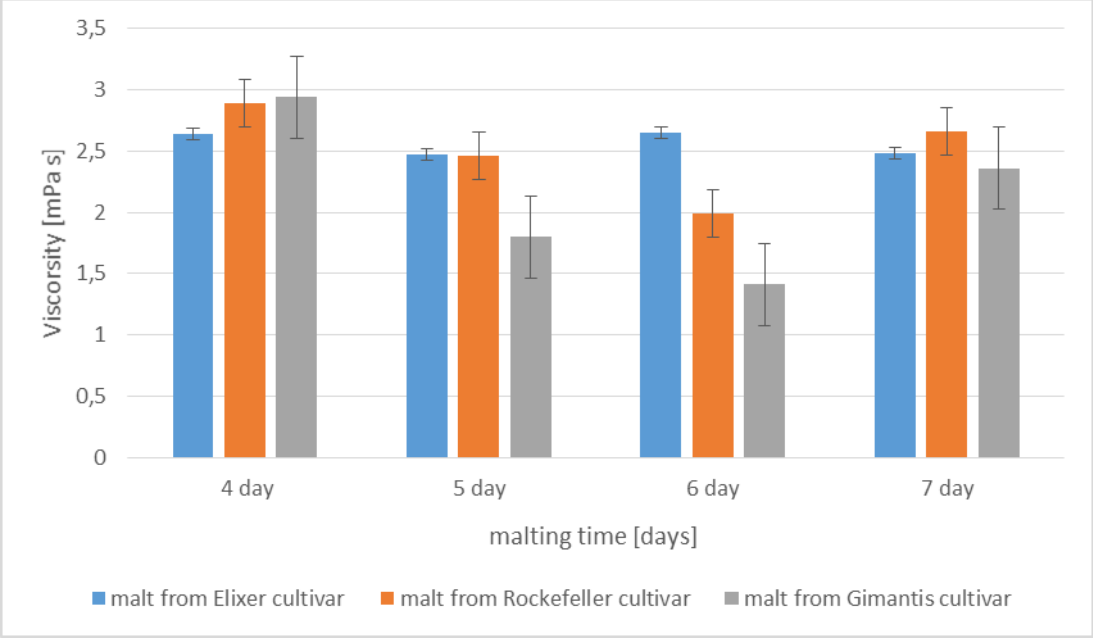


Figure 2. Effect of the malting time and wheat variety on wort viscosity

Effect of the wheat variety and malting time on the quality of the wheat malts

Mean total malting loss in the case of *Elixer* and *Rockefeller* wheat varieties amounted to nearly 7.5% d.m., where approximately half of the decrease in grain weight was associated with formation of root; on the other hand, slightly higher total malting loss was observed in wheat grain of *Gimantis* variety. The malt produced from the examined wheat varieties was found with good quality parameters, except for Kolbach Index whose value was slightly higher, but still acceptable for malt-houses in the case of *Elixer* and *Rockefeller* variety. The malt produced from the third wheat variety investigated here was found with very high Kolbach Index (50.49%) which is a disqualifying value for wheat malt (Table 6).

Similar malting losses were identified in 4- and 5-day malts, however 96-hour long process was related to lower quality parameters of the obtained malts (mainly for extract potential and degree of final fermentation) due to insufficient intensity of enzymatic transformations (Table 7). Longer duration of the malting process corresponded to higher grain weight loss, however no positive effects of malting time were observed either in 6-day or in 7-day malts with regard to the quality of the obtained malt. Given this, longer duration of malting process, exceeding 5 days, is ineffective from economic point of view, because each additional day of the process leads to increasing loss of malt weight, while the quality is not improved.

Table 6. Effect of the wheat variety on the mean values of the malt quality parameters and malting losses

Parameter	Winter wheat *Elixer* variety	Winter wheat *Rockefeller* variety	Winter wheat *Gimantis* variety
Total loss [% d.m.*]	7.44^{b}	7.43^{b}	7.74^{a}
Weight loss - roots [% d.m.]	3.87^{b}	3.95^{b}	4.17^{a}
Weight loss – grains [% d.m.]	3.56^{a}	3.48^{a}	3.58^{a}
Total protein in malt [% d.m.]	11.50^{a}	11.72^{a}	10.61^{b}
Kolbach Index [%]	44.74^{b}	44.39^{c}	50.49^{c}
Diastatic power [ºWK]	326.50^{a}	302.00^{c}	312.17^{b}
Extract potential in malt [% d.m.]	86.47^{a}	85.35^{b}	86.96^{a}
Final attenuation [%]	79.88^{a}	80.43^{a}	80.33^{a}

*various letters in the rows show significance of the differences at α=0.05
* [% d.m.] – percent of dry matter

Table 7. Effect of the malting time on the mean values of the malt quality parameters and malting losses

Parameter	4-days malt	5-days malt	6-days malt	7-days malt
Total loss [% d.m.*]	4.95^{d}	5.48^{c}	9.04^{b}	10.67^{a}
Weight loss – roots [% d.m.]	2.67^{c}	2.73^{c}	5.20^{b}	5.39^{a}
Weight loss – grains [% d.m.]	2.29^{d}	2.75^{c}	3.84^{b}	5.28^{a}
Total protein in malt [% d.m.]	11.54^{a}	11.41^{ab}	11.14^{bc}	11.00^{c}
Kolbach Index [%]	41.98^{d}	46.16^{c}	48.59^{b}	49.43^{a}
Diastatic power [ºWK]	310.11^{a}	317.11^{a}	313.67^{a}	313.33^{a}
Extract potential in malt [% d.m.]	84.79^{b}	86.24^{a}	87.28^{a}	86.72^{a}
Final attenuation [%]	78.81^{b}	81.12^{a}	81.63^{a}	79.28^{b}

*various letters in the rows show significance of the differences at α=0.05
* [% d.m.] – percent of dry matter

CONCLUSION

Selection of adequate wheat variety and optimum malting time is the most important activity ensuring high quality of the produced malt; it also determines the production and quality of wheat beer. The findings of the experimental study assessing selected wheat varieties, show that 5-day malting process made it possible to produce good quality wheat malts, with optimum malting losses. Extending the malting time to seven days did not significantly affect the quality of the malts, while the increase in grain weight loss is an economically unjustified factor. Similar malting losses were observed in the case of *Elixer* and *Rockefeller* wheat varieties and the malts produced from these varieties were found with high technological parameters. Slightly higher malting losses were identified in the malts obtained from wheat of *Gimantis* variety which also had very high contents of soluble protein (mean of 5.34% d.m.) and Kolbach Index (mean of 50.49%); this may reflect high proteolytic activity during the malting process. In view of the above, the process of micro malting should be modified for wheat of *Gimantis* variety in order to reduce activity of enzymes from the group of proteases.

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